A Laboratory Study of the Charging/Discharging Mechanisms of a Dust Particle Exposed to an Electron Beam

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With the newly discovered rings of Jupiter, dust storms on Mars, close encounters with comets, and Hubble photos of dust rings around stars, understanding the interaction of micron sized particles or "dust particles" with different space and planetary environments has become an important area of research. One particular area of interest is how dust particles interact with plasmas. Studies have shown that charged dust particles immersed in plasmas can alter plasma characteristics, while ions and electrons in plasmas can affect a particle's potential and thereby, its interaction with other particles. The basis for understanding these phenomena is the charging mechanisms of the dust particle, specifically, how the particle's charge and characteristics are affected when exposed to ions and electrons. For example, when electrons collide with a dust particle, secondary electrons can be produced from the surface of a particle and can affect the surrounding plasma.

At NASA Marshall Space Flight Center, a laboratory experiment has been developed to study the interaction of dust particles with electrons. Using a unique laboratory technique known as electrodynamic suspension, a single charged particle is suspended in a modified quadrupole trap. The trap or electrodynamic balance is composed of three electrodes. An alternating voltage is applied to the center ring electrode and a DC voltage is applied to the top and bottom electrode. The alternating voltage is analogous to a potential well where the point of lowest potential is at the geometric center of the balance. An incoming charged particle will find the point of lowest potential and become “trapped” or suspended in the center of the balance. The DC voltage is applied to counter the effect of gravity. Once suspended, the particle is then exposed to an electron beam to study secondary electron emission due to collisions of energetic electrons. The change in the particle's charge, approximations of the primary and secondary electron currents, and the secondary electron yield are calculated.

To date, most of the testing has been done using irregularly shaped positively charged aluminum oxide particles. Using the balance electrical parameters, the charge, mass, and potential are calculated. The diameter is calculated by varying the alternating voltage or frequency in air until the particle's motion becomes unstable. This is called the spring point measurement. Based on nine separate particle tests, the diameter of the particles is approximately 1.5 ± 0.4 microns. Typical charges for these particles are found to range from 6.9×10^{-16} Coulombs to 1.2×10^{-15} Coulombs ± 22%, the masses of the particles range from 9.0×10^{-12} to 1.1×10^{-11} grams ± 17%, and the surface potentials range from 7 Volts to 19 Volts ± 24%. For the above calculations, it is assumed that the aluminum oxide particles have a spherical geometry.

Each particle is exposed to the electron beam with energies ranging from 100 eV to 3 keV under a vacuum in the order of 10^{-6} torr. Typical exposure time varies from a few minutes to an hour. Out of the nine particles exposed to the electron beam, it was observed that most of the particles steadily lost surface charge over time as in Figure 1. The charge is shown for the times when the primary electron beam current is constant.

The secondary electron emission or current is determined by the relation

$$I_{se} = I_e - \frac{\Delta q}{\Delta t} \tag{1}$$

where I_e is the measured primary electron current, $\Delta q/\Delta t$ is the measured change of the particle's charge as a function of time, and I_{se} is the secondary electron current. Note that I_{se} includes other

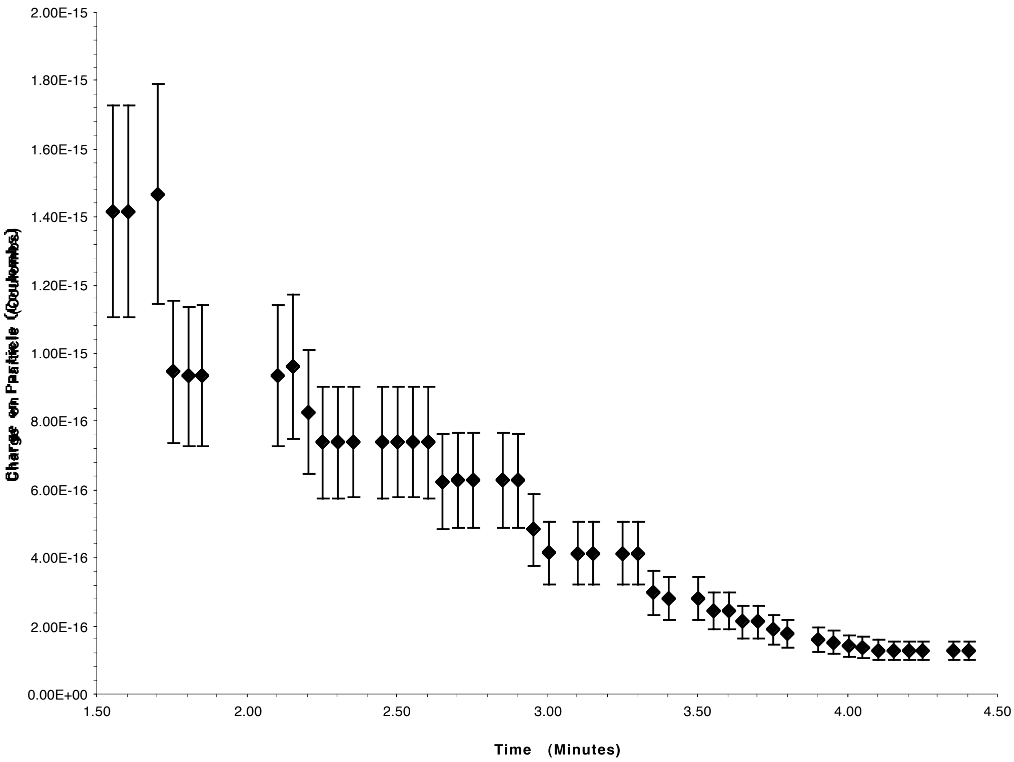

Figure 1. One particle's charge as a function of time when exposed to 200 eV electron beam

currents such as currents due to tunneling electrons and back scattering electrons since they cannot be distinguished in this particular experimental setup.

From the nine particles tested so far, the incident primary electron beam currents range from 7.0×10^{-7} to 1.4×10^{-4} pA ± 10%, $\Delta q/\Delta t$ range from 5.1×10^{-7} to 3.0×10^{-5} pA ± 31%, the secondary electron emission currents range from 2.0×10^{-7} to 1.3×10^{-4} pA ± 33%.

The secondary electron emission yield as a function of electron beam energy is plotted for the nine particles in Figure 2. The majority of the particles have an approximate yield of 1.0 which means there is a close one-to-one ratio between the secondary electron current to the primary electron current. Testing is still continuing with the aluminum oxide particles.

Future plans for this experiment include studying the interaction of dust particles with ultraviolet radiation. A deuterium lamp is to be used to study the effect of photoionization. Also using the same electrodynamic balance technique as mentioned above, a new laboratory experiment is currently being developed that will use infrared light to study the optical properties of interplanetary dust particles. This will include finding extinction coefficients of the dust particles.

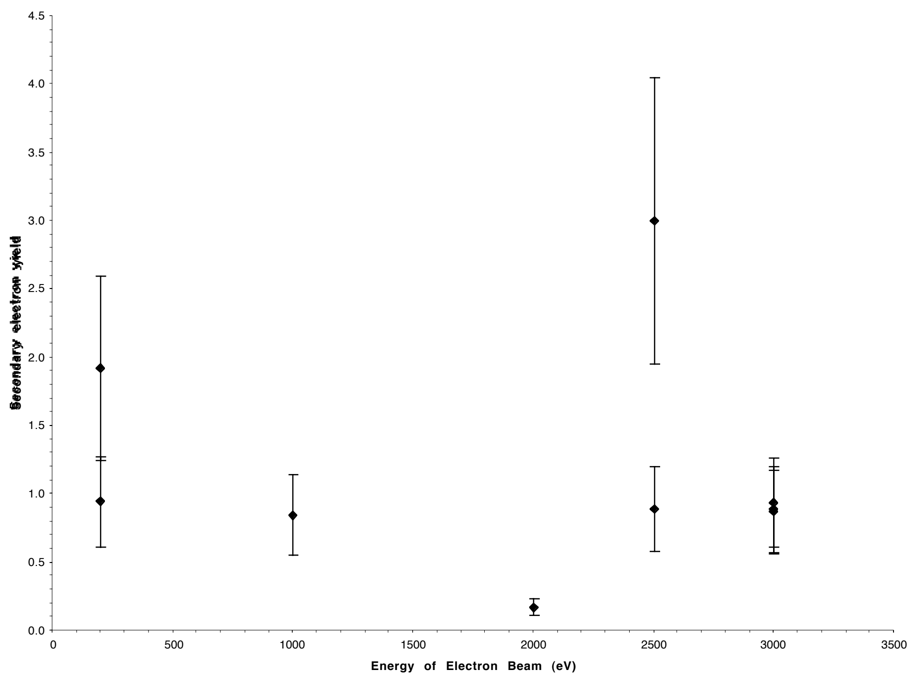

Figure 2. Secondary electron emission yield vs. Energy of electron beam.